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A Re-Evaluation of the US EPA Radon Risk Categorization for Unicoi County, Tennessee.

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A Re-evaluation of the US EPA Radon Risk Categorization for Unicoi County, Tennessee

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ABSTRACT

A Re-evaluation of the US EPA Radon Risk Categorization for

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Effective risk communication is based on appropriate risk characterization. A reevaluation of the 1987 US EPA radon risk categorization of Unicoi County, Tennessee was conducted using in-home radon concentrations, determined in a long-term monitoring study. Radon concentrations were measured in 69 homes using Electret Passive Environmental Radon Monitors (E-PERM's), following standard methods. Radon concentrations determined in this study (avg. 4.03 $\pm$ 3.04) were significantly higher than those measured in the USEPA study (avg. 1.96 $\pm$ 1.08). Using this study's data, the risk categorization was recalculated with the US EPA Radon Index Matrix Model. The model re-categorized Unicoi County from a moderate to a high risk zone classification. These results suggest that the health risks associated with in-home radon concentrations are inaccurately categorized and communicated to the citizens of Unicoi County, Tennessee.

DEDICATION

I would like to thank God for giving me the life to live, my wife, my family, and friends.

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CHAPTER 1

INTRODUCTION

Radon is the only naturally produced class 'A', known human carcinogen (EPA 1991). It is a radioactive, inert, gaseous, nonmetallic element that is undetectable by the human senses (EPA 1992a). Radon is produced in the decay series of uranium and, more directly, by the degradation of radium (EPA 1990a, 1990b; Mosby-Year Book Inc. 1998; Viera 2000).

The United States Surgeon General's National Health Advisory maintains that radon gas in the home is a national health problem that is responsible for thousands of deaths each year (Cohen and Associates 1992; Anonymous 2000). The National Academy of Sciences, the Committee on the Biological Effects of Ionizing Radiations, and the United States Environmental Protection Agency (US EPA) all agree that exposure to radon gas and the alpha emitting radon decay products (RDPs) cause over 14,000 preventable deaths per year in the United States (US National Research Council 1988; Cohen and Associates 1992; Southern Regional Radon Training 2002).

After exposure to radon or the RDPs, which occurs primarily through inhalation and ingestion the alpha emitters can then be absorbed into the tissues of the body. When the degradation of the alpha emitters occurs, the cells adjacent to them can be irradiated (US National Research Council 1999). Health effects from cell irradiation can include: cancer induction, genetic disease, teratogenesis, and degenerative changes. The target tissues for cancer induction and degenerative changes are located in the respiratory system, skeletal system, and the liver (US National Research Council 1988).

Because of the health effects associated with exposure to radon and RDPs, the 1988 Indoor Radon Abatement Act directed the US EPA to identify geographical areas with the potential for elevated indoor radon concentrations within the United States (US) (EPA 1993). The US EPA Radon Index Matrix Model was developed to determine these geographical areas. The model used five factors: indoor radon measurements, domicile foundation types, aerial radiometric surveys, geology, and soil parameters, to determine the radon risk classification on a county-by-county basis throughout the US (EPA 1992a, 1993). The US EPA Radon Risk Zone Map is a representation of the results obtained from the matrix model, which were categorized into three risk zones; zone 1 or high risk areas which have a predicted average indoor radon concentration above 4 picoCuries per liter of Air (pCi/L), zone 2 or moderate risk areas which represent a radon risk potential between two and four pCi/L, and zone 3 or a low risk radon areas which are characterized by an average indoor radon concentration which is less than 2 pCi/L.

The indoor radon risk categorization for Unicoi County was derived, in part, from the information obtained in the 1986-1987 US EPA, State Residential Radon Survey of Tennessee. The radon survey employed fourteen in-home radon short term monitoring (STM) measurements in the determination of Unicoi County's zone 2, moderate risk classification. Data obtained from this monitoring showed that the arithmetic mean of the radon measurement concentrations was 1.9 picoCuries per Liter (pCi/L), and the maximum concentration was 4.9 pCi/L (EPA 1993).

Statistics on radon monitoring obtained through the public awareness programs of the Tennessee Radon Program (TRP) revealed evidence of a higher in-home radon concentration for citizens of Unicoi County than the 1987 US EPA radon risk zone classification designated. The statistical analysis that the TRP utilized for Unicoi County was obtained from short term monitoring performed through Air Chek Inc. The TRP purchased Air Chek Inc. monitors to distribute in different public awareness radon programs in the state. The purchase price of the monitors included the required laboratory analysis of the monitors, which determines the radon concentration of the home. The calculated radon concentration was returned to the individual that deployed the monitor, and the descriptive statistics for each county was compiled, as a courtesy from Air Chek Inc., to the TRP.

The descriptive statistics obtained from the TRP public awareness programs, represented a mean indoor radon concentration of 4.2 pCi/L and a maximum concentration of 24.1 pCi/L. The categorization that was determined by using the US EPA's Radon Index Model did not appear to correlate to the in-home radon concentrations measured in Unicoi County through the TRP.

The US EPA radon index matrix model risk classification for Unicoi County determined a moderate risk or zone 2 classification. The TRP was apprehensive because of the observed differences between the in-home radon concentrations of the US EPA's data (N 14, mean 1.9 pCi/L, maximum 4.9 pCi/L) and the TRP data (N 54, mean 4.2 pCi/L, maximum 24.1 pCi/L). The program was also concerned with the health outcome from an under-representation of the risk exposure to radon, a class 'A' known human carcinogen. They concluded that more radon monitoring was required to determine the accuracy of the US EPA's Radon Index Model and to ensure that the human health risk exposure to the citizens of Unicoi County, Tennessee was accurately categorized (Appendix A: Personal communication with Marsha Malone-White 2001)

CHAPTER 2

LITERATURE REVIEW

The History of Radon

In 1899, while trying to measure the radiation that was emitted from radium, Pierre and Marie Curie observed an interesting phenomenon. The radioactive gas emitted from radium remained reactive for almost a month (van der Krogt 2003). In 1900, the German physicist Friedrich Ernst Dorn confirmed their finding by using a more active radium compound. Dorn, who is often considered the discoverer of radon, called the highly radioactive gas a "radium emanation" (Ramsey and Collie 1904; LaFavore 1987). The name was derived from the Latin "emanare" – to elapse and "emanatio" – expiration. In 1908, the radium emanation was renamed niton from the Latin "nitens", which means shining, by Sir William Ramsay and Robert W. Whytlaw-Gray, who isolated the element and determined it to be the densest gas known (Ramsay and Whytlaw-Grey 1910; van der Krogt 2003). In 1923, the International Committee for Chemical Elements and the International Union of Pure and Applied Chemistry chose the name radon, which was submitted by Gerhard Schmidt and Benjamin Adams to identify the colorless, odorless, tasteless, nonmetallic, nonflammable, inert, radioactive noble gas derived from radium (LaFavore 1987; Mosby-Year Book Inc. 1998; van der Krogt 2003).

Radon and its radioactive decay products constitute approximately half of the radiation dose that is received by the general population over a lifetime (UNSCEAR 1994). This chemically inert and electrically uncharged element has the atomic number of 86 and the atomic weight of 222. It is recognized on the periodic table of elements by the symbol Rn (Joesten and Wood 1996).

The radioactive element radon can be condensed to a transparent liquid and to an opaque, glowing solid. Radon has a melting point of –71 degrees Celsius (°C) and a boiling point of –62°C. The gas has a density of 9.73 grams per liter at 0°C at one atmosphere, which makes it the densest gas known. Of the 23 isotopes of radon, 18 are radioactive (Nazaroff and Nero 1988; EPA 1990b). Radon is undetectable to human senses and can only be detected and measured through the use of radon specific testing devices (EPA 1992a).

Radon has been used for several beneficial purposes. It has been used as a cancer treatment, a tracer in leak detection (EPA 2001), and in radiography as a pre-determinant for both earthquakes and volcanic activity (Garcia et al. 2000; Planinić et al. 2001; Fujiyoshi et al. 2002). Radon has also been extensively used for uranium exploration (EPA 1990c). Radon is, however, a class 'A' known human carcinogen (EPA 2001) and the second leading cause of lung cancer in the United States; the number one cause is cigarette smoking (EPA 1992b; Viera 2000).

Sources

Radioactive elements are characterized by their half-lives or "rate of decay" (Gollnick 2000). Every radioactive element has its own half-life, which is the amount of time that is required for half of the atoms of the element to degrade into a non-radioactive element (Gollnick 2000; Gao et al. 2002). Ultimately, all radioactive decay processes (half-lives) will continue until inert, non-radioactive nuclides are formed (Gao et al. 2002).

The radioactive gas radon is ultimately produced by the natural degradation of uranium (EPA 1990c; Viera 2000). (Appendix B: Uranium-238 Decay Chain) Uranium is a primal element, and, therefore, was present when the earth's crust was created. It is found in soil, water, and rocks. The uranium concentrations present in the soil and rock of any geographical region is typically comparable (Otton et al. 1992).

Radon gas is directly derived from the decay of Thorium-232 and Uranium-238, which are also naturally occurring elements found in rock, water, and soil (EPA 1990b, 2001; Nebel and Wright 1996). Thorium-232 decays into radon-220, a radon isotope called thoron. Radon-220 has a radioactive half life of 55 seconds and represents a small source of radon exposure when compared to the exposure obtained from the Uranium-238 decay into Radon-222, which has a half-life of 3.8days (EPA 1990b; Otton et al. 1992). Because of the higher risk associated with exposure to the longer half-life Radon-222, it is specifically addressed in most US EPA documents and in this document any references to radon will imply the radioactive radon-222 (EPA 2001).

The half-lives of the radon decay products (RDPs) range from 0.000164 parts of a second for the polonium-214 isotope up to 27 minutes for a lead-214 isotope (Gollnick 2000). Radon has a half-life of 3.8 days (EPA 1990b; Otton et al. 1992). The half-life of uranium, a primal element and the ultimate grandparent compound of radon, is approximately 4.49 billion years (EPA 1990c; Denagbe 2000). Because of the lengthy half-life of uranium, the natural production of radon is considered to be everlasting.

Radioactivity

During the decay process, radiation is emitted from the nuclei of the atom. There are three principle types of radiation emission: gamma rays (γ), beta (β), alpha (α) and (Gao et al. 2002). Gamma rays contain no mass or charge. The rays travel at the speed of light and are also called photons (Cohen and Associates 1992). The photons travel more deeply into objects than the alpha or beta particles. The gamma radiation, even though it has the ability to pass through the human body, causes very little damage to the living tissue (Gao et al. 2002).

Beta particles are electrons that travel at high speed for short distances. These particles have only a moderate ability for tissue penetration (Gao et al. 2002). The beta particles do cause damage to living tissue; however, about 20 times less than the alpha particles (Lafavore 1987).

Each alpha particle is equivalent to a helium nucleus (two protons and two neutrons). When an alpha particle is expelled from the nucleus of a radioactive element, the element changes to a new, lighter element called an isotope, and the alpha particle becomes helium gas. When radioactive elements undergo this process in nature, it is identified as natural radioactivity (Metivier 2002). When this process occurs in the body (in vivo), the emission of the alpha particle can damage intracellular deoxyribonucleic acid (DNA), which can result in malignant neoplasm growths, genetic disease, teratogenesis, and degenerative changes (Hei et al. 1997; Krewski et al. 1999).

The greatest risk from alpha radiation to the general public is derived from radon gas. Contact with alpha radiation can occur through any exposure route; however, because of the alpha particle's low penetrating power, the majority of the injury from alpha radiation occurs thru an exposure into the single cell region of the respiratory system. Other probable target tissues are located within the liver and skeletal system. Once inside the body the radiation derived from the alpha particle is considered the greatest health risk associated with exposure to radon (Lafavore 1987). Alpha radiation can cause a great deal of damage to any living tissue that is located within a small distance from the atom that created the particle (Metivier 2002). There is not a specific subtype of cancer associated with exposure to alpha radiation; however, the alveolar region of the lungs is most susceptible to the alpha exposure.

Radon Studies

There have been numerous epidemiological studies conducted on uranium hard rock miners. As early as 1930, researchers had determined a positive correlation between the inhalation of radon gas and the increased occurrences of lung cancer among the miners (Lundin et al. 1969; Roscoe et al. 1989; Lindsey and Scott 1996). It was not until 1952 that William F. Bale and Frantisek Béhounek independently identified the alpha particles from radon and the radon decay products as the cause of the lung cancer (Lundin et al. 1969; National Radiation Protection Institute 2003).

The radon related health risk analyses for domestic exposures, which used the miner's health data, encountered several extrapolation dilemmas. The dilemmas included: (1) using the health data obtained from predominantly working age men on risk evaluations for women, children, and elderly of the general public; (2) the vast majority of the miners sampled were smokers; (3) and the average radon concentrations and exposures that the miners received were considered many times larger than the domestic population would ever receive in the home (US National Research Council 1988; Cohen and Associates 1992). These extrapolation dilemmas were determined to have caused some of the domestic population studies to be unsuccessful in showing a significant positive correlation between the domestic population's cancer risk and exposure to radon, as was shown with the miner's exposure data (Cohen 1993; Létourneau et al. 1994). Additional factors that have been shown to influence the outcome of radon related health risk studies include: the long latency period associated with the growth of malignant neoplasm's, as well as the other uncertainties or variability's that are encountered in any human health risk assessment (IARC 1988; Krewski et al. 1999; Fields et al. 2000).

Although there have been extrapolation issues by using the miner's data on the general public, most studies have shown a positive correlation between radon exposure and the increased occurrence of lung cancer (Samet 1989; Pershagen et al. 1994). It has been scientifically proven that intracellular DNA can be damaged as a result of contact with an alpha particle, as with those involved in radon's radioactive decay sequence (Kendall and Muirhead 1997; Krewski et al. 1999).

The US EPA estimates that radon is responsible for approximately 14,000 deaths per year (d/y), with that estimation ranging between 7,000 – 30,000 d/y (EPA 1992a; Hopke et al. 1995). The US National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation (BEIR) used the epidemiological studies of underground miners exposed to radon and developed human health risk models for predicting radon exposure risk to the general population. The two preferred radon risk models that were produced by BEIR, determined estimates of 15,000 and 22,000 radon induced lung cancer deaths in the US annually (US National Research Counsel 1999).

All major health organizations, including the Centers for Disease Control and Prevention, The American Lung Association, and the American Medical Association, agree that radon-related deaths are preventable by decreasing the concentration and the exposure to the alpha particles released by radon and the radon decay products (EPA 1992a; Conrath and Kolb 1995). The Surgeon General Health Advisory on radon maintains that there is a national health problem associated with indoor radon gas; that radon exposure causes thousands of deaths each year; and elevated radon concentrations can be found in millions of homes in the US. Therefore, all homes should be tested for elevated radon concentrations and when the concentrations are confirmed, the situation should be rectified (Cohen and Associates 1992; Anonymous 2000).

Exposure

Naturally occurring radon gas is responsible for 55 % of the total annual radiation exposure to the general public of the United States (US) (UNSCEAR 1994; Gollnick 2000). The location of greatest opportunity for radon exposure to the public is found in the home (Nazaroff and Nero 1988; Anonymous 2000). Tighter construction and better insulation techniques have inhibited radon from exiting the home once inside (EPA 1994, 2001). Because of radon's density, it tends to concentrate in the lower levels of a structure (EPA 1995; Anonymous 2000). Although uranium is ultimately the only source of radon, there are four contributors to indoor radon concentrations in the home, they are: soil gas, emanation, diffusion, and water (Cohen and Associates 1992).

Approximately 90 % of radon's indoor air concentration, is contributed from soil gas entry into the home (Greene 2000). Soil gas is a complex mixture composed of nitrogen, oxygen, water vapor, carbon dioxide, and radon gas (Nazaroff and Nero 1988; Greene 2000). Most soils have between 15 and 55 % pore (or void) space (EPA 1993). Soil gas is present underground in these pore spaces between the soil particles and can be found within the crevices located in rock formations (Nazaroff and Nero 1988; Cohen and Associates 1992). Radium, which is considered the direct parent compound of radon, is also present in the majority of soils and rock formations (EPA 1990a). When radon gas is formed in the ground, its mobility is greatly increased if it becomes a component of the soil gas (Viera 2000). The in-door concentration and mobility of radon in soils is also dependent on: the soil's uranium content and distribution or "source strength," the soils porosity and affinity for gas movement or "permeability," and the moisture content of the soil (Otton et al. 1992; EPA 1993).

Emanation, or the direct release of radon, can occur from uranium contaminated building materials in the home (Cohen and Associates 1992). Primarily, stone, concrete, block, brick, and sheetrock are responsible for radon emanation. This contribution to the total in-home radon concentration is small, typically less than five percent (EPA 1991).

The process of radon diffusion into the home, due to a concentration gradient, is also a contributing factor of the indoor radon concentrations. This radon entry method can occur via holes in the foundation or through the foundation material itself and is considered separate from any diffusion from the soil gas. This source for radon entry is responsible for less than four percent of the total in-home radon concentration (Cohen and Associates 1992).

Radon can also enter a home through the water source (Otton et al. 1992). Typically water-borne radon is only a concern for individuals with an untreated well water supply, because the radon is not allowed to easily escape to the atmosphere, as allowed with a surface water supply (Lindsey and Scott 1996). The release of water-borne radon into a house will increase the air-borne radon concentrations. The conversion factor for calibrating how water-borne radon will affect the indoor air radon concentration is 10,000 units of radon per liter of water is equivalent to one unit of radon per liter of air (Cohen and Associates 1992). The radon concentration in the water source would need to be extraordinarily high to have a noticeable effect on the indoor concentration. For this reason, water-borne radon is responsible for less than one percent of the in-home total radon concentration (EPA 1991).

The primary route of radon exposure is through inhalation (EPA 1990b). As explained by Lindsey and Scott (1996) exposure to alpha radiation from radon or the alpha-emitting radon decay products (RDPs) results in a variety of health risks of concern. The insult begins with intracellular DNA damage and can result in cancer. Alpha radiation has the ability to damage cells in close proximity to the particle's degradation. The cell repair mechanisms are not absolute the more damage that occurs to a cell the more likely the repair mechanisms will be ineffective in the repair.

As described in Caserett and Doull's Toxicology 6th edition (2001), in most cases injured cells are repaired or eliminated. When alterations in the cell do occur; the mutation may remain silent (not affecting the function of the cell), the mutation may inhibit cell survival, or the worse case scenario would be the replication of the expressed mutation, causing a reprogramming of the cell. Every mitosis division that the damaged cell undergoes increased the potential for the mutations to increase.

RDPs have a higher potential for initiating the toxicological health risk than the radon gas (Pershagen et al. 1994, Lindsey and Scott 1996). The short-lived RDPs can be inhaled into the respiratory system unattached or attached to other particles such as smoke, dust, lint, or biological aerosols (Cohen and Associates 1992). After inhalation, the RDPs can come into contact with single cell membrane in the alveolar region of the lungs. The radon decay products are ionically charged heavy metals particals. The particulate matter is capable of adhering to the mucus lining in the respiratory system, through chemical and physical attraction, as well as impaction. The adherence increases the RDPs retention time in the respiratory system. The RDPs short half-lives also increases the potential of a decay event occurring while they are inside the lungs. If the RDP is associated with the lung tissue when the decay occurs, the energy from the event will be transferred to the attached cell, possibly initiating a chain of events that will end in respiratory cancer. The inert noble gas, radon, does not display the chemical attractive forces, nor would physical adherence to the lung surface be a factor; therefore, there is high probability that it could be exhaled before a degradation event occurred (EPA 1990b).

US EPA Radon Risk Potential Zone Map

Sections 307 and 309 of the 1988 Indoor Radon Abatement Act (15 U.S.C. 2661-2671) directed the US EPA to identify geographical areas with the potential for elevated radon concentrations within the US (EPA 1993). The US EPA Radon Risk Potential Zone Map was created to accomplish the task. The map was completed in 1992 and identified the areas that were associated with elevated radon risk on a county-by-county basis (EPA

1992a). (Appendix C: United States Environmental Protection Agency Radon Risk Zone Designation Map)

The radon risk zones were categorized using five factors: in-home radon concentration measurements, domicile foundation types, aerial radiometric surveys, geology, and soil parameters (EPA 1993). The risk factors were used to categorize each US county into one of three zones. Zone 1, Zone 2, and Zone 3, which have predicted indoor radon concentrations of greater than 4 pCi/L, 2-4 pCi/L, and less than 2 pCi/L, respectively (EPA 1992b). (Appendix D: Tennessee Radon Zone Map)

The US EPA's testing within the US, resulted in a national average in-home radon concentration of approximately 1.25 pCi/L of air (Viera 2000). Additionally, it was decided that 4pCi/L would denote the activity where action should be taken to decrease the in-home radon concentration. The "action level" is approximately equal to the disintegrations of nine atoms of radon per-minute in a liter of air (Lindsey and Scott 1996). The US EPA's studies estimate that 1 out of 15 homes have elevated, above the action level, radon concentrations (Nazaroff and Nero 1988). The US EPA has documented other studies that present evidence that the ratio of homes with radon concentrations above the action level is as high as one-in-three (Anonymous 2000).

Tennessee Radon Program

The Tennessee Department of Environment and Conservation (TDEC) developed an in-door air program under the Division of Air Pollution Control. The name of the statewide program is the Tennessee Radon Program (TRP). The mission of the program is to conduct activities that lead to the reduction of indoor air radon concentrations to the same concentration as the ambient air (Tennessee Radon Program 2003).

TRP has compiled an in home radon concentration database to compare with the US EPA radon risk zone classifications, for the majority of the counties in Tennessee. The database is used to compare the categorizations determined by the US EPA radon index model to actual in-home radon concentration averages for the Tennessee counties. The US EPA radon categorization for Unicoi County, Tennessee determined a moderate risk zone, 2-4 pCi/L. However, the radon concentration results from TRP's monitoring project of Unicoi County had a mean of 4.2 pCi/L and a maximum of 24.1 pCi/L.

Objectives

The observed differences between the 1987 US EPA and the 1992- 2002 TRP radon concentration databases caused concern at the TRP, which was focused on the accuracy of the US EPA Radon Index Model. To ensure a proper radon risk categorization and communication for the citizens of Unicoi a re-evaluation of the index model was required. The specific objectives included:

1. collect in-home radon concentration data in 69 Unicoi County, Tennessee homes,
2. make statistical comparisons between the radon concentration data from: the 1987 US EPA study, the 1992-2002 TRP data (analyzed by Air Chek Inc.), and the 2002 UCTRS data,
3. use the existing US EPA Radon Index Matrix Model to recalculate the radon risk potential for Unicoi County with the UCTRS data, and

4. determine if Unicoi County’s radon risk potential has been correctly categorized as a zone 2, moderate radon risk.

CHAPTER 3

METHODS AND MATERIALS

County Study Location

Unicoi County, Tennessee is located in the northeastern region of Tennessee. Rugged mountains and narrow valleys characterize the topography of Unicoi County. The county land mass is approximately 186 square miles. Approximately half of the land mass is uninhabited public lands administered by the National Park Service (NPS). The NPS land is located in the southern region of the county. The 2000 census determined Unicoi County's population as 17,667, with a population density of 95 people per square mile (p/m^2). Considering, that the NPS land is uninhabited, and, that there are approximately 11.7 square miles of agricultural lands in Unicoi County, would more than double the population density ratio for the populated areas of the county (US Department of Agriculture 1997). Therefore, the UCTRS decided to position the monitors in locations that were highly populated, as the US EPA did in their study.

The UCTRS monitoring zone was bordered to the north by the Carter county line and to the south by the NPS land. The western boundary was the eastern aspect of Buffalo Mountain and the eastern boundaries were the Stone and Unaka mountain ranges. This monitoring zone encompassed the townships of both Erwin and Unicoi and included several other small communities including Love Station, Banner Hill, Fishery, and Marbleton.

Geological Formations

The monitoring zone is located in the Unaka Mountains or "Blue Ridge" physiographical province. The geological formations of the monitoring zone include Honaker Dolomite, Shady Dolomite, as well as Rome Formations and Erwin Formations (EPA 1993). The formations included in the study zone are from the Cambrian geologic period of the Paleozoic era (King and Ferguson 1960). As suggested by their names, Shady and Honaker Dolomite formations are characterized by the type and abundance of dolomite and limestone, contained within them. The Rome Formation also has the characteristic of limestone and abundant dolomite in the Eastern Region of Tennessee, primarily the Unaka Mountains. The Erwin Formation is characterized by sandy shale and sandstone (King et al. 1944). The limestone and dolomite geology have a positive correlation to radon concentrations (Cohen and Associates 1992). Although the sandy shale and sandstone do not share the positive correlation to the radon concentration, they do have the characteristics that increase the ability for radon transport (King et al 1944; Cohen and Associates 1992). All of the formation types present in the UCTRS possess radon transport or production ability. (Appendix E: Geologic Map for Unicoi County, Tennessee)

Radon Measurements

The UCTRS used "S" Chamber Electret Passive Environmental Radon Monitors (E-PERM) to determine the indoor radon concentrations of the homes in the study. (Appendix F: Schematic of the Electret Passive Environmental Radon Monitor (E-PERM) "S" Chamber) The study employed a long term monitoring (LTM) sequence of greater than 91 days. The E-PERM monitor, as described by Kotrappa et al. (1988) and Kotrappa et al. (1990), consists of a small chamber with a removable Teflon disc called an electret that carries a quasipermanent electric charge. The electric charge from the electret disc generates an electrostatic field inside the monitor capable of collecting ions of the opposite charge. Upon activation, the monitor allows for radon gas to diffuse into the chamber through a semi-permeable membrane. RDP's are not capable of traversing through the membrane into the E-PERM. The RDP's that are present have occurred through the decay of the radon gas inside the monitor. Ions that are generated during the degradation of radon and the RDP's are attracted to the charged surface of the electret. When the ions contact the charged surface, the result is a decrease in the surface voltage of the electret.

The dielectric material of the electret is capable of maintaining an electrical charge almost indefinitely (Surette and Wood 1993). The charged electrets of the UCTRS were, however, measured on an Electret Surface Potential Voltmeter or "electret reader" within minutes of the E-PERM's activation to decrease any chance of voltage loss to the electret during transit to the study home. The time and date of the deployment for each monitor was documented for use in the E-PERM radon concentration calculation formula. The activation period ended after each monitor was exposed for greater than 91 days.

At the end of each activation period the E-PERM was recovered and the electret voltage charge was re-measured. The time and date were also documented again. The duration that each monitor was activated and the pre and post monitoring electret's voltage were input into the E-PERM radon concentration calculation formula to determine the radon exposure concentration measurement for each home. (Appendix G: Electret Passive Radon Monitor (E-PERM) Radon Concentration Calculation Formula)

Sampling Sites

The research design entailed the placement of 69 E-PERM monitors inside study homes in Unicoi County, TN. A power analysis estimated that 67 monitorings were required to detect differences with a 95% confidence. The researcher used professional associates as primary contacts. The primary contacts were selected due to their associations with assorted communities of Unicoi County. These primary contacts introduced the researcher to potential study participants, and then the researcher discussed and explained the program and the responsibilities to the potential participants, following all Institutional Review Board, Human Subject Research Training guidelines.

The participants' responsibility was to allow the researcher to place an E-PERM in their home and they were required to allow the monitor to remain undisturbed for a period greater than 91 days (EPA 1992b). The participants were allowed to choose whether they were informed of the results from their radon monitoring or not. The researcher's responsibility to the participants was to guarantee that their identities would remain confidential and that any personal information obtained would not be distributed.

Monitor Deployment

In the study homes the monitor placement was determined with consideration to the US EPA guide “Protocols For Radon and Radon Decay Product Measurements In Homes” which includes:

1. measurement should be made in the lowest level of the home than contains a room that is regularly used,
2. measurements should not be made in kitchens, laundry rooms, or bathrooms,
3. a position should be selected where the detector will not be disturbed,
4. the monitor should not be placed in a draft caused by HVAC systems or doors and windows,
5. the measurement location should not be within 3 feet of a door or window or within 1 foot from an exterior wall, and
6. the detector should be at least 20 inches from the floor and 4 inches from other objects, the optimal height is considered “the breathing zone”.

Analysis of Contributing (US EPA Radon Risk Matrix Model) Factors

The US EPA developed the Radon Risk Matrix Model, which is used to determine a radon risk zone classifications for each county in the US. (Appendix H: United States Environmental Protection Agency Radon Index Matrix Model) The model included five factors that are determined to impact in-door radon concentrations. The information obtained for each factor was county specific and they include: in-door radon concentration averages, soil permeability, geological formation types, home architecture foundation types, and aerial radiometric surveys (EPA 1993).

The UCTRS explored the availability of other existing data sets for radon concentration measurements in Unicoi County. Only one other data set was located, at Air Chek Inc. Mike DeVaynes, the resident statistician at Air Chek Inc. graciously allowed the use of the raw dataset for Unicoi County, Tennessee, in the statistical analysis of this thesis.

The three data sets (UCTRS, US EPA, and Air Chek Inc.) were separated into the different categories so that statistical comparisons could determine if differences were present in the radon concentrations averages of the dataset.. The categories were: types of monitoring (long term vs. short term), townships (determined by zip code), geological factors, and the seasonality of the monitoring. The type of monitoring and the township datasets were also used in combination with the geological data to determine if any other tendencies in the radon concentrations could be determined. The UCTRS did not delineate the home foundation structure types in this study, nor did the Air Chek Inc. data set.

Statistical Analysis

Basic descriptive statistical analyses were carried out on the three data sets. A log transformation procedure was then performed on the data, which achieved a normally distributed data set. The parametric statistical tests of Analysis of Variance (ANOVA) and the Students t-test were used to establish statistical differences determined by using a p value ≤ 0.05. The Fisher's and Tukey's multiple comparison tests were used to determine differences in the ANOVA comparisons.

Quality Assurance /Quality Control

Monitoring with the E-PERM

As described in the Indoor Radon Measurement Device Protocol for E-PERM monitoring, there are five areas of quality assurance: calibration, known exposure detectors, duplicate detectors, control detectors “blanks”, and routine instrument checks (EPA 1992b). The E-PERM detectors and the electret surface potential voltage reader are required to be calibrated once every 12 months. The calibration for the electret surface potential voltmeter and the known exposure detectors occurred less than one month prior to the commencement of the testing period. (Appendix I: Electret Passive Radon Monitors (E-PERM) Certified Readings)

Known exposure detector analysis requires a rate of three spikes per one hundred activated E-PERM’s. A minimum number of spikes are three per year and there is a maximum number of six per month. The E-Perm Monitors that were borrowed from the TRP to conduct this study are contractually maintained within the maximum known exposure detector requirements.

One duplicate detector was placed per every 10 detectors activated, which was used to calculate percent error for the monitoring regiment. The protocol requires for control detectors placement to occur for approximately 5 % of the monitorings, or a maximum of 25 per month, whichever is least. The UCTRS monitored with control detectors at a frequency of 1 control per every 10 activated monitors. The routine instrument checks of zeroing the electret voltage reader and analyzing with a reference electret should occur weekly to ensure proper operation of the reader; however, these instrument checks were performed before each monitoring day began.

Interference-Resistant Testing

There were five factors used in an attempt to conduct interference free testing:

1. education of the study participants on; the health risks of Radon, and that tampering with the detectors could increase the radon concentration, participants had the option of “handling” an inactive monitor before testing began,
2. instrument placement indicators were used at each location,
3. non-resealable tape was used on the electret disc to deter tampering with the canister,
4. zip-tie locking mechanism on canister ensured that the canister could not be shut, and
5. confidentiality of personal information, location, and the radon concentrations, only this researcher had the ability to identify site locations and the corresponding radon concentrations.

Documentation

The electret voltage readings were documented on E-PERM data collection sheets in the field. The electret serial number, the voltage reader identification number, the reference electret serial numbers, the day, time, and temperature as well as the name and address of the homeowner were also documented on the collection sheets. At the research facility the information was converted to an Excel spreadsheet. The spreadsheet was used to calculate the total amount of time the monitor was deployed and the voltage drop over time. The E-PERM Concentration Calculation formula was then performed to determine the average radon concentration over the monitoring period for each home.

CHAPTER 4

RESULTS

In the spring of 2002, the UCTRS monitored the radon concentration in 69 Unicoi County, Tennessee homes. A long-term monitoring program (greater than 91 days) was performed using E-PERM "S" chamber monitors. The results from the UCTRS program were compared with the US EPA (1987) database for Unicoi County. The US EPA data were used in the calculation of the radon index matrix model, which determined the US EPA radon risk zone classification. The data obtained through the UCTRS were used in a recalculation of the radon index matrix model.

Indoor radon concentrations are impacted by many factors. To obtain a more accurate comparison between the factors of the two data sets (UCTRS and US EPA), the availability of other Unicoi County datasets was explored; however, the only other dataset was possessed by Air Chek Incorporated, located in Fletcher, North Carolina. Up until this time, Air Chek Inc. had only allowed the descriptive statistics of their data to be distributed; however, they permitted access to their radon dataset for this study. The Air Chek data set allowed for additional comparisons to be made between the radon concentration factors of the US EPA (1987) short term monitoring program, and the UCTRS (2002) long term monitoring regiment. The database from Air Chek included monitoring data that were compiled between the years 1990 – 2002. All of the Air Chek monitoring data were derived from short-term, activated charcoal adsorption devices, these were the same type of measuring devices that the US EPA used in the 1987 study (EPA 1992b).

The frequency distribution plot for the three data sets, display similar trends between the UCTRS and the Air Chek radon concentrations. The majority of their radon concentration data points are displayed within the medium-risk (2 – 4 pCi/L) and high-risk (> 4pCi/L), radon risk zones. The reverse is seen in the US EPA data set, where the majority of the radon concentration data points are grouped in the low radon risk zone (0-2 pCi/L) (Figure 1).

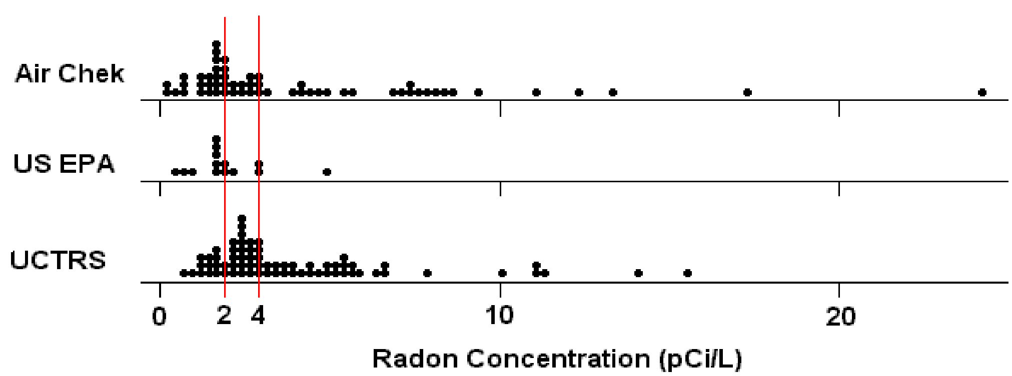

Figure 1 Frequency Distributions and Radon Concentrations measured in picoCuries per liter of air (pCi/L) for Air Chek Inc., the United States Environmental Protection Agency (US EPA), and the Unicoi County Tennessee Radon Study (UCTRS).

A comparison of the UCTRS and the Air Chek Inc. descriptive statistics indicate similar trends, although the two data sets were obtained by different types of radon monitoring. The UCTRS incorporated E-PERM monitors and a long term monitoring sequence, while the Air Chek data set was determined by activated charcoal adsorption devices and a short term monitoring sequence. Conversely, the descriptive statistics are not similar between the Air Chek and the US EPA monitoring sequences. Both were, however, determined by the same type of monitors (activated charcoal adsorption devices) and used the same time frame (STM) for their monitoring sequences (Table 1).

Table 1. Descriptive Statistics of Radon Concentrations in picoCuries per liter of air for Unicoi County Tennessee Radon Study (UCTRS), United States Environmental Protection Agency (US EPA), and Air Chek Inc. Datasets.

Group	*N*	Mean	Geo Mean	Median	St. Dev.	Minimum	Maximum
UCTRS	69	4.03*	3.24*	2.8	3.04	0.6	15.5
US EPA	14	1.96	1.7	1.8	1.08	0.5	4.9
Air Chek	58	4.39*	2.88*	2.7	4.45	0.3	24.1

*Significant Difference ($p<0.05$) compared against the corresponding US EPA value

Matrix Model

The UCTRS re-evaluated the five variables of the US EPA radon risk classification matrix model. The variables used in the matrix model were: soil permeability, geological formation, aerial radiometric surveys, foundation types of the home, and the actual indoor radon concentrations. The UCTRS program radon concentration average for Unicoi County was used in place of the US EPA data.

Information pertaining to the other four variables was assessed for use in the re-calculation of the matrix model.

The geological portions of the model include soil and geological formation types. These two factors of the matrix model are unchanged from the original calculation. The soil permeability in the residential areas in Unicoi County, Tennessee has not been re-sampled since the original mapping in 1944, which was used in the radon zone classification determination. Therefore, the original soil permeability data were used in the matrix model re-evaluation (Personal communication with Nathan Hartgrove 2002). The geological maps used in the US EPA matrix model calculations were also unchanged for Unicoi County since the original mapping in 1966 (Personal communication with Mark Braswell 2003).

The aerial radiometric surveys have been recalculated and remapped since the US EPA zone map classification. (Appendix J: National Uranium Research Evaluation (NURE) Map) Slight corrections in the average gamma background radiation exposure were needed. The higher elevations of Tennessee required an additional 0.12 micro Roentgen per hour (μR/h) for the background gamma radiation exposure (Gogen and Goldin 1981). This updated background exposure change is a 1.2 % increase from the previous value.

The data gathered for the original matrix model showed that the majority of homes in Unicoi County had basements. The Air Chek data did not delineate the architectural foundation type of the homes monitored in its data sets. The UCTRS also did not document the individual foundation type of the homes in the study. The Unicoi County Assessor of Property confirmed, through personal experience, that the majority of the homes in Unicoi County have a basement or a crawlspace. (Appendix K: Personal communication with W. J. Gaines 2003)

The UCTRS average radon concentrations and the additional updated matrix factor data were used in the recalculation of the radon index matrix model. The data from the matrix model were then used to determine the UCTRS's radon risk zone classification. The resulting radon risk zone classification produced revealed a higher risk zone than the US EPA data had determined. The UCTRS radon risk zone category was a Zone1 classification.

Further Analysis of the UCTRS' Data

The log-transformed, indoor radon concentration data obtained from the UCTRS were plotted on a geological formation map. A comparison was then made between the average radon concentrations and the different geologic formations that were found within the UCTRS sampling site area (Table 2). The UCTRS radon data were also compared to sampling site clusters to determine if any high radon concentration areas could be identified.

Table 2. Log Transformed Radon Concentration Data Distribution within the Geologic Formations Present in the Unicoi County Tennessee Radon Study (UCTRS).

Geological Formations	Zone	*N*	Geo Mean	SD
Honaker Dolomite	1	39	1.27	0.73
Shady Dolomite	2	7	1.09	0.43
Rome Formation	3	10	0.98	0.51
Erwin Formation	4	13	1.07	0.56

* Significant Difference ($p \leq 0.05$)

The four geological formation types in the monitoring area were: Honaker Dolomite, Shady Dolomite, Rome Formation, and Erwin Formation. The geological radon concentration data were log transformed and statistically analyzed using an analysis of variance test (ANOVA) or a t-test depending on the number of zones that were analyzed. The results of the geologic formations are presented in Table 3. The geological formations were also analyzed after being divided into three groups that included: the two dolomites (placed into one group because of their similarities) compared against the remaining two groups (the Rome Formation and the Erwin Formation). Finally, the Dolomites and the Rome Formation were included in one group because Rome Formations, located in the highland regions of Tennessee, are accepted as having abundant amounts of Dolomite deposits (King et al. 1944; King and Ferguson 1960). The different approaches for the analysis of the geologic data produced the same outcome. There were no significant differences in the log transformed mean radon concentration found in the geological formations.

Table 3. Unicoi County Tennessee Radon Study (UCTRS) Geological Formation Zones and Monitoring Cluster's, Statistical Test's and P Values.

Geological Zones	Statistical Tests	P Value
1 vs 2 vs 3 vs 4	ANOVA	P = 0.520
(1,2) vs 3 vs 4	ANOVA	P = 0.403
(1,2,3) vs 4	t test	P = 0.089
Clusters		
(1-7)	ANOVA	P = 0.269

* Significant Difference ($p \leq 0.05$)

An ANOVA was performed on the radon concentrations from the seven different groups of homes or "clusters" within the monitoring zone to determine if any cluster locality correlated with higher radon concentrations. The statistical analysis determined that there were no statistical differences in the clusters (p = 0.269). The results of the monitoring cluster's radon concentration data can be seen in Table 4.

Table 4. Unicoi County Tennessee Radon Study (UCTRS) Log Transformed Radon Concentrations within Monitoring Clusters.

Cluster	*n*	Geo Mean	SD
1	2	1.02	0.69
2	28	1.12	0.57
3	9	1.17	0.79
4	12	1.36	0.8
5	5	0.58	0.37
6	4	1.12	0.63
7	9	1.49	0.56

*Significant Difference (p< 0.05)

Compiled Data Set Contributing Factors

Contributing factor comparisons were also statistically analyzed using log transformed radon concentration data obtained from the three data sets. Comparisons were made among the compiled radon data set (UCTRS, US EPA, and Air Chek) and the contributing factors of: (1) the seasons of the year, (2) the townships of Erwin and Unicoi, (determined by the zip codes), and (3) long-term verses short-term monitoring data.

The data sets were compiled into one group to compare the seasonality of the radon concentrations, the results can be seen in Table 5. An ANOVA was performed on the compiled data group and it determined no significant differences in the compiled data sets radon concentration for the seasons ($p = 0.171$). The Air Chek Inc. data set was analyzed independently using an ANOVA on the log-transformed data. It determined a p value of $p = 0.035$, indicating that a significant difference could be found in the data group. A Fishers Multiple Comparison Test determined that significant differences were present between the seasonal comparisons of winter (geometric mean (GM) = 1.52) versus spring (GM 0.33), and also with the comparison of winter (GM 1.52) versus summer (GM 0.65). The cooler winter season exhibited higher radon concentrations.

The US EPA data only incorporated two seasons. A t-test determined that there was a statistical difference between winter (GM 0.86) and spring (GM 0.29), again a higher radon concentration was determined in the winter. The UCTRS data were obtained only in the spring; therefore, no seasonal analysis could be performed on the UCTRS's data alone.

Table 5. Log Transformed Radon Concentrations for Unicoi County, Tennessee Determined within the Seasons of the Year.

Group	Season	*N*	Geo Mean	SD
UCTRS	spring	69	1.18	0.65
US EPA	winter	6	0.86	0.41
	spring	8	0.29	0.59
Air Chek	winter	17	1.52	0.83
	spring	5	0.34	0.33
	summer	7	0.66	1.18
	autumn	29	1.01	0.93
Compiled Set	winter	23	1.35	0.79
	spring	82	1.04	0.7
	summer	7	0.66	1.18
	autumn	29	1.01	0.93

* Significant Difference ($p \leq 0.05$)

Statistical analysis were performed by t-tests on the log transformed radon concentration data relative to the townships can be seen in Table 6. All the analyses showed that there were no significant differences found in the township comparisons.

Table 6. Log Transformed Radon Concentrations within Townships of Unicoi County, Tennessee.

Group	Township	*n*	Geo Mean	SD	p value =
UCTRS	Erwin	39	1.12	0.61	0.49
	Unicoi	30	1.24	0.7	
US EPA	Erwin	11	0.46	0.63	0.17
	Unicoi	3	0.8	0.23	
Air Chek	Erwin	42	1.15	0.83	0.34
	Unicoi	16	0.83	1.2	
Compiled set	Erwin	92	1.06	0.75	0.91
	Unicoi	49	1.07	0.88	

* Significant Difference ($p < 0.05$)

The ANOVA comparison of the UCTRS long-term monitoring compared to the short-term monitorings of the US EPA and Air Chek determined that there was a significant difference in the data sets. The Fishers multiple comparison test determined that there were significant differences in the comparisons of the UCTRS (LTM) versus the US EPA (STM) and the comparison of the US EPA (STM) versus the Air Chek (STM) data. No significant difference was determined between the comparison of UCTRS (LTM) compared with the Air Check data (STM) (Table 7).

Table 7. Log Transformed Radon Concentrations for Long Term Monitoring and Short Term Monitoring performed within Unicoi County, Tennessee.

Group	Monitor	*n*	Geo Mean	SD
UCTRS	LTM	69	1.17	0.65
US EPA	STM	14	0.53	0.58
Air Chek	STM	58	1.06	0.95

*Significant Difference ($p \leq 0.05$)

Chapter 5

DISCUSSION

Radon Risk Communication

The principal objective of the UCTRS was to determine if the 1987 US EPA Radon Index Matrix Model accurately communicated the general population's human health risk associated with radon exposure in Unicoi County, Tennessee. The purpose of risk communication is to inform individuals about the existence, nature, severity, and the acceptability of an environmental risk (Molak 1997). Effective risk communication is based on an appropriate risk characterization. In the risk characterization it is critical to determine radon's existence and exposure.

Radon is a natural degradation product from the decay of uranium. The production of radon has occurred since the world began (approximately 5 billion years ago) and will continue indefinitely (Cohen and Associates 1992). The primary route of exposure is obtained through the respiratory system; however ingestion and dermal exposures also occur. For the non-mining general population, the location of greatest concern for radon exposure occurs within the home.

Most structures (i.e. homes) will exert a negative pressure on the ground beneath them, by hot air rising and exiting the building (the thermal stack effect). As the release of the hot air occurs, simultaneously, more air must enter the building. The air entering the building is often a result of the negative pressure exerted on the soil beneath the structure. A component of this air obtained from the soil or "soil gas" is the class "A" known human carcinogen radon. The ability of the soil gas to enter the building is the basis for the domicile foundation type consideration in the US EPA matrix model.

The type of foundation has a major effect on the pressure exerted on the ground, and, therefore, the ability of radon to enter the home (EPA 1991). Once the radon is inside the home, due to its density, it tends to accumulate in the lower regions. As the radon accumulates, its concentration can increase dramatically (EPA 1993). The average ambient background radon exposure for the USA is 0.4 pCi/L (EPA 1992a). The average indoor radon concentration is 1.3 pCi/L; however, there have been indoor concentrations that exceeded 1000 pCi/L (Cohen and Associates 1992).

The dose response curve that represents the health effects associated with radon gas exposure is considered to be linear with no threshold, any exposure is considered unacceptable. Indoor radon concentrations; however, can only be decreased to ambient (or background) radon concentrations. Therefore, the objective of home mitigation is to decrease the indoor radon concentrations until it is equal to ambient in order to minimize the human health effects from the indoor radon exposure.

The major response from an exposure to radon gas is cancer. The primary carcinogenic response is elicited in the alveolar region of the lungs. As with many carcinogenic responses, the latency period is relatively long (approximately 40 years). The latency period increases the difficulty of a direct and positive correlation between exposure to radon gas and the resulting malignant neoplasm, increasing the importance of accurately communicating the radon human health risk (U.S. National Research Council 1999). The identification of areas with the potential for elevated radon concentrations is not an accurate representation of the actual in-home measurements. Homes with elevated radon concentrations must be identified on an individual basis and mitigated to ensure maximum human health protection. After all, radon is totally undetectable to human senses, and as the Surgeon General stated, "measurement is imperative to identification" (Cohen and Associates 1992; Anonymous 2000).

The UCTRS research was the first study performed in Unicoi County, TN since the 1987 US EPA program. The results of the UCTRS research risk categorization for Unicoi County will be used by the TRP in an attempt to increase the support for radon risk communication, measurement and mitigation in Tennessee.

It is important to recognize that the radon average obtained in the UCTRS is only a representation of the radon concentration for one county, for a state, which has 95 others. The results; however, indicate that a low sampling size has a direct affect on the average radon concentration, therefore it should be noted that there were 64 other counties in Tennessee with an equivalent number of monitors (or less) used in their risk categorization. When the other 49 states in the US are considered the potential misrepresentation of the human health risk exposure to radon gas is huge.

Radon Index Matrix Model

The 1987 US EPA Radon Index Matrix Model was used to identify and quantify the factors involved in indoor radon concentrations. These factors included aspects of radon production and transport as well as actual indoor radon measurements in homes of the individual county being categorized.

The initial objective of this study was to create a radon concentration data set for homes in the county. This objective was achieved through the deployment and recovery of 69 E-PERM, 'S' chamber, long-term radon monitors. Upon recovery of the monitors, the electrets were measured for voltage reduction and the E-PERM radon calculation formula was performed to determine each home's average radon concentration. The county's average radon concentration was determined to use in the UCTRS 2002 Radon Index Matrix Model risk zone re-categorization.

The categorization of Unicoi County, TN by the US EPA Matrix Model in 1987, determined a zone 2, moderate radon exposure risk. The 2002 UCTRS re-evaluated each of the factors in the model and when more accurate data was available replaced the 1987 data. The one significant difference in the matrix model re-categorization was the indoor radon gas concentration average derived from the UCTRS data. The result of the matrix model recalculation determined the radon risk zone classification to be the highest category for the citizens of Unicoi County, a zone 1 rating. The change of the risk zone categorization was because of the difference in the sampling sizes between the US EPA and the UCTRS.

UCTRS Contributing Factors

Radon Concentration and Sample Size

The comparison in average radon concentrations of the UCTRS (mean= 4.0 pCi/L) and the Air Chek (mean = 4.4 pCi/L) data sets displayed higher mean radon concentrations than the US EPA (mean = 1.9 pCi/L) data set. A power analysis performed on the populations determined little statistical power in the precision and reliability of the US EPA data set (n= 14, power = 0.54); however, because of the sample size of the UCTRS and the Air Chek data sets they were each calculated to have reliable statistical power and precision (n = 69, power = 0.9988 and n = 58, power = 0.9952, respectively). Therefore, the lower radon concentration average of the US EPA data set was affected by the small monitoring sample size that did not have enough samples to accurately represent the counties average radon concentration (power = 0.9516 would have been achieved by a sample size of n = 37).

The US EPA's small sample size affect the risk zone categorization, this conclusion is supported by comparisons made between other contributing factors of the data sets. The US EPA and the Air Chek data sets employed the same types of monitoring devices (activated charcoal) and the same type of monitoring timeframe (short-term monitoring); however, analysis determined that the geometric means of the two data sets were statistically different. The comparison between the Air Chek and the UCTRS data sets, which had similar sample sizes, determined that the geometric means of the two data sets were not statistically different, although the two sets employed different monitoring devices (activated charcoal and E-PERM) and different monitoring timeframes (STM and LTM, respectively). Analysis of these factors reinforced the conclusion that the large sample size resulted in a more accurate determination of the average radon concentration for Unicoi County.

Geology

Contributing factors examined during the UCTRS were analyzed to determine if trends in the radon concentrations could be established within the geological formations, the clusters of samples, or the townships that were located within the monitoring area.

Abundant evidence is available to support the role of geological formations in the source strength and the transport mechanism of radon (King et al. 1944; EPA 1990b; Cohen and Associates 1992). This study, however, was unable to establish correlations between the radon concentrations and the different: geological formations, monitoring clusters, or townships that were present in the UCTRS sampling area. There are many explanations for these results.

The US Geological Maps that were used in the matrix model were created in 1966 and are still considered the best source for geological formation location information; however, it is well noted that there were many assumptions in the research used in the creation of the map (King et al. 1944; King and Ferguson 1960). Often, there were many miles between the different sampling locations that were used for the map determination. Because of this fact the geological formations of the map can be inaccurate by hundreds of yards (King et al. 1944). The only way to determine the geology at a particular site is to do a bore drilling at that location (Personal Communication with Dr. Peter Lemiski 2003).

The four different geological formations in the UCTRS were similar in chemical composition. Three of the formations were composed of carbonaceous rock, dolomite, and limestone, all of which are associated with elevated radon concentrations on a local scale (Cohen and Associates 1992). The other types of geology located within the study site included carbonaceous: sandstone, shale, and siltstone, which allow for easy transport of radon through the soil (Cohen and Associates 1992). Therefore, all of these geologic formations were determined to have an influence on the production of or the transport of radon (King et al. 1944; Cohen and Associates 1992; EPA 1993; Anderson 2001).

Because of the similarity within these formations it would be unlikely that there were differences in the in home radon concentrations within the interconnected and similarly structured geological regions, especially when the geological formations exact locations could not be accurately identified.

The geology in an area is a primary consideration for in home radon concentrations. Although, as gas, radon has the ability to be transported great distances through many different geologic formations (Riley et al. 1999; Garcia et al. 2000; Camplin 2000; EPA 2001). The geological formations found within the UCTRS have a porous composition, which allows for easier radon transport (King and Ferguson 1969; EPA 1993). The porosity of the formations would also decrease the ability to identify the geological area that was responsible for a particular radon concentration.

The ability to locate clusters of homes with elevated radon concentrations is inhibited by the similar composition of the geological formations in Unicoi County. This fact was also apparent in the attempt to determine elevated radon concentrations within the geological formations, though it would seem probable to find areas of elevated radon, and has been accomplished many times (Dudney et al. 1990; Singh et al. 2002). There is also abundant evidence that determines, due to the porosity of the soils and fissures of rock formations and numerous other factors, homes located in a close proximity to one another are more likely to have different radon concentrations (EPA 1991, 2001; Keskikuru et al. 2000; Godoy et al. 2002). Therefore, locating clusters of homes with elevated radon concentrations within a sampling area would require extensive monitoring.

The three data sets (UCTRS, US EPA, and Air Chek) used zip codes to denote township boundries in order to determine if either township in Unicoi County had a significantly higher radon concentration. The results of the comparisons displayed no significant differences in any of the township analyses. The geological formations, the soil types, the sample sizes, as well as topographical variations of the two townships are all very similar, which would reduce the ability to determine differences in the township's average radon concentrations. The similarities in the information for the townships would, however, support the US EPA's decision to denote the radon risk zones into county designations. The inability to precisely discern elevated radon locations would also support the Surgeon General's statement that the only way to know if you have elevated radon concentrations is to do radon specific monitoring.

Seasonality

The data sets (US EPA, Air Chek, and UCTRS) were analyzed to determine if seasonality could be established in the radon concentrations of the homes monitored. The results of a Tukey's pairwise comparison from the compilation of the data sets concluded higher radon concentrations in the winter versus the summer. Air Chek Inc. possessed the only data set with true seasonal representation. Therefore, the Air Chek data were analyzed alone. A Fisher's pairwise comparison results displayed differences in winter versus spring and summer. The data obtained through the UCTRS correlate with the previous research on indoor radon concentrations from Fleischer and Turner in 1984 as well as Wilkening and Wicke, in 1986, which show elevated radon concentrations have seasonal variations. Under typical conditions, higher radon concentrations will be present in the cooler months primarily because of closed house conditions and the effect of the house on the soil (Nazaroff and Nero 1988; Riley et al. 1999; Steck et al. 1999; Godoy et al. 2002; Southern Regional Radon Training Center 2002). There have been other studies, however, that have shown higher radon concentrations in the warmer seasons, this has been associated with the type of geological formations present in the monitoring area (Hess et al. 1985; Dudney et al. 1992; Southern Regional Radon Training Center 2002). As seen in the environmental studies on indoor radon concentrations performed by Dudney et al. and Riley et al. in 1992 and 1999 respectively, the geology of the study area can cause elevated radon concentrations to be present in summer versus winter. The presence of elevated radon concentrations in the warmer seasons is a characteristic of Karst geological formations (Southern Regional Radon Training Center 2002)

Typically, the highest seasonal radon concentrations are expected in winter and spring, when closed house conditions are exhibited. The warm air inside the house rises and escapes through the chimney, vents in the roof, and any alternate means. The escaping air will exert a negative pressure on the soil below the home, thereby drawing soil gas (which carries radon) into the home (Southern Regional radon training 2002).

The rain and snow (typically seen in the cooler seasons) also play a role in channeling radon toward the home. When the ground is saturated by rain or capped by snow, it can inhibit the release of radon into the environment. The inhibition will force radon to find alternate means of escaping the soil. The primary alternate soil gas escape route will be through the drier ground beneath a house, which will channel the radon directly into the home. During these times, the radon concentration of a home can increase enormously (EPA 1991; Cohen and Associates 1992; Hopke et al. 1995; Denagbe 2000).

Assuming the linear model with no threshold for radon exposure, monitoring tests should be performed in the cooler seasons (winter and spring) to ensure adequate human health risk characterization and communication. The data obtained in the UCTRS did not have seasonality, the entire monitoring sequence occurred in the spring. The spring of 2002 was unseasonably warm, which could have affected the radon concentrations obtained in the UCTRS. However, if the warmer temperatures did affect the indoor radon it would decrease the radon concentrations. This only adds validity to the UCTRS's conclusion that the US EPA matrix model underestimated the human health risk of radon exposure.

Long-Term Monitoring Compared to Short-Term Monitoring

STM was originally used to determine indoor radon concentrations. Issues arose, however, on the use of the STM results for the representation of the mean in-door radon concentration, which is used by the US EPA for regulatory purposes (EPA 1995). As shown in studies performed by the Southern Regional Radon Training Center (2002), even using year round STM sequences to determine an average in home radon concentration can miss episodes of elevated radon concentrations, and, thereby, miss-represent the exposure risk of indoor radon gas to the homeowner. Continuous year-round monitoring, therefore, is the most accurate measurement of indoor radon concentrations (Cohen and Associates 1992, EPA 1992a; Southern Regional Radon Training 2002). However, due to the time and expense required for continuous year round monitoring the US EPA recommends that LTM sequences be performed in the cooler months to determine a representative in-home radon concentration (EPA 2001; Southern Regional Radon Training 2002). A LTM is deemed to accurately represent the average yearly in-home radon concentration.

Statistical Analyses performed through this study, comparing the LTM dataset of the UCTRS to the Air Chek Inc. STM data, has shown statistically similar results were obtained from the different types of monitoring timeframes when an adequate sample size was used. Thus, determining that under the appropriate monitoring conditions and with an adequate sample size either timeframe will determine a statistically similar response (or radon concentration). Upon verification, this could have a great deal of impact to radon inspection techniques used in regulatory determinations. The funding, material, and time that are required for the LTM of radon could be used to do more in-home monitoring within a STM time sequence, thereby, increasing the radon sample size, and producing a more accurate risk communication for the general public.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

Data analyzed by the UCTRS determined that the STM (Air Chek) and LTM (UCTRS) studies delivered statistically comparable radon concentration results. Furthermore, the UCTRS demonstrated that there are many factors involved in indoor radon concentrations determinations; however, the ultimate determination relies on individual indoor radon monitoring.

The UCTRS determined that the small monitoring sample size (n = 14) used by the US EPA in the original 1987 US EPA radon matrix model was a significant cause of the underestimated radon risk categorization for the citizens of Unicoi County, Tennessee. The larger sample size (n = 69) used in the UCTRS matrix model calculation, was crucial in the re-categorization of Unicoi County as a Zone 1 radon risk designation. In the 1987 US EPA radon risk categorization, 62 of the 95 counties located in Tennessee, used fewer indoor radon tests than Unicoi County. Furthermore, the results of a power analysis determined that 37 monitors were needed to obtain statistical power, thereby, questioning the validity of the communicated radon risk zone designations for over 87 percent of the counties in Tennessee, which is only one of the fifty states.

The ultimate objective of the UCTRS was to determine if the radon risk for the citizens of Unicoi County had been accurately categorized. The outcome from the UCTRS research determined that the categorized risk communication of the 1987 US

EPA Radon Index Matrix Model understated the human health risk communication to the citizens of Unicoi County, Tennessee for the Class ‘A’ known human carcinogen radon.

Recommendations

Further approaches to this study could include:

- cluster testing for elevated radon concentrations, this would require all houses within an area to be monitored and compared,
- seasonal weather variations could be researched by studying a small number of houses with multiple monitors per house (including continuous monitors) to compare how the radon concentrations fluctuate when conditions change, the comparisons of closed and open house conditions should be studied as well, and
- another extension of this study would be in the comparison of both the long and short term monitors within individual homes (again including a continuous readout monitor), as an addendum to this study, an adequate population size would be required.

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Appendix A

Correspondence with Marsha Malone-White, Environmental Program Manager of the Tennessee Radon Program

STATE OF TENNESSEE
DEPARTMENT OF ENVIRONMENT AND CONSERVATION

Tennessee Radon Program
Nashville Environmental Assistance Center
711 R.S. Gass Blvd.
Nashville, TN 37216

May 18, 2001

Mr. Grant Parsons
502 NC 80
Bakersville, NC 28705

RE: Radon Testing Partnership Study
Upper East Tennessee

Dear Mr. Parsons,

The Tennessee Radon Program (TRP) is very pleased to participate as a sponsor in your proposed radon testing study. As we discussed during our April meeting, there is considerable concern that the current EPA radon risk assessment assigned to the Upper East Tennessee region is not a true reflection of the actual risk of radon occurrence and associated health risks. As we have discovered in numerous counties of Tennessee, radon risk assessment may well be much higher than projected, as indicated by actual test results tracked by Air Chek® test data.

There are several items I would like to recommend to you as you undertake this project. Although we have discussed each of these, please feel free to contact me if there are any questions.

- Short term radon testing only provides a "snap shot" in time for radon levels in a structure. I strongly recommend you conduct long term testing, which will provide far more accurate radon concentration results, using EPA approved devices. A minimum testing period of 91 days is required. The Tennessee Radon Program will be glad to assist by offering the use of our E perm® Long Term Testing devices.

G. Parsons
Page Two
May 18, 2001

- I would advise you to obtain Radon Certification training in both testing and mitigation. I consider this training essential to ensuring valid testing and a clear understanding of the many aspects of the Radon issue. Both trainings are being offered soon, mitigation the week of June 22 and radon testing the week of August 17, 2001.

- Regardless of the testing device chosen, it is imperative that you follow an established quality assurance /quality control program (QA/QC). You will learn more details about QA/QC in the courses discussed above. For the purpose of your study, I recommend utilizing duplicates and spike calibrations.

- The Conference of Radon Control Program Directors (CRCPD), through State radon programs, is offering mini grants for the study of radon or the promotion of radon awareness. Although the amounts are very small, an award would help to cover your study expenses. I am enclosing the application. As you will note, the TRP is very pleased to sponsor you and in your application for this grant.

Mr. Parsons, the TRP is very excited by your level of knowledge, interest and concern on the issue of radon. We encourage your efforts and are here to assist you in any way possible. Please do not hesitate to call upon us.

Sincerely,

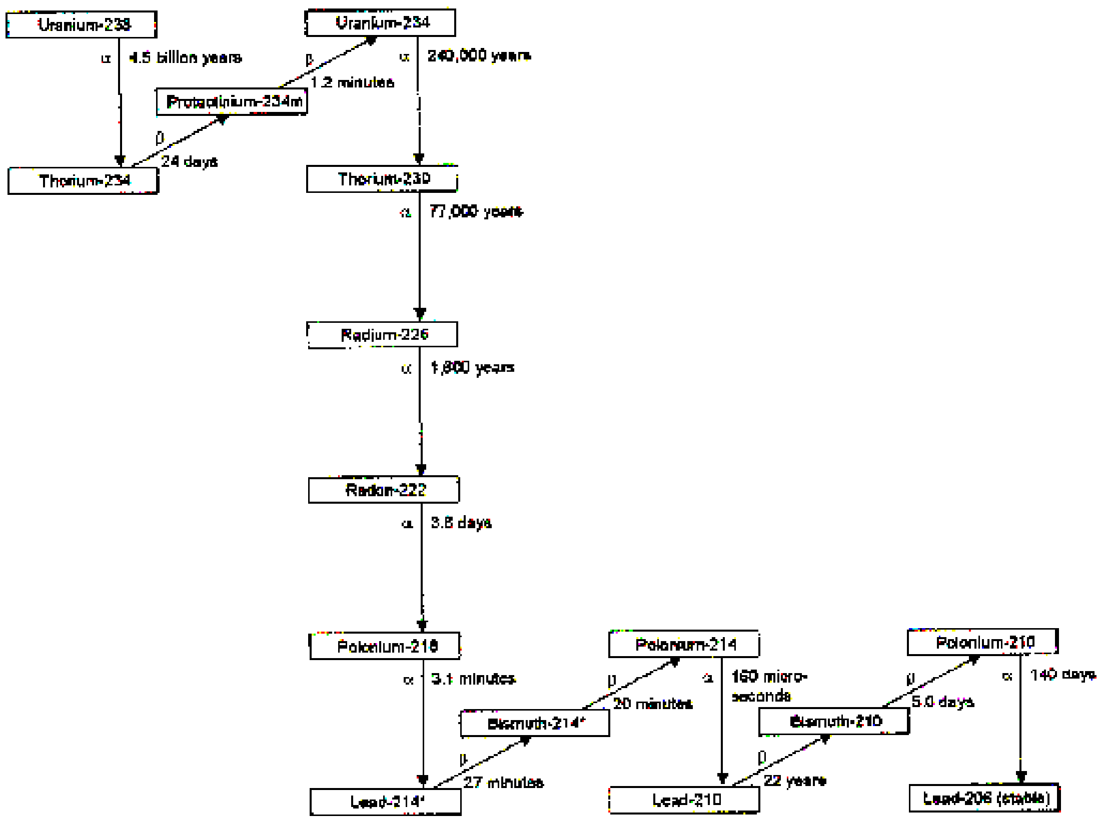
Marsha Malone-White

Marsha Malone-White
Environmental Program Manager
Tennessee Radon Program

Enclosure

Appendix B

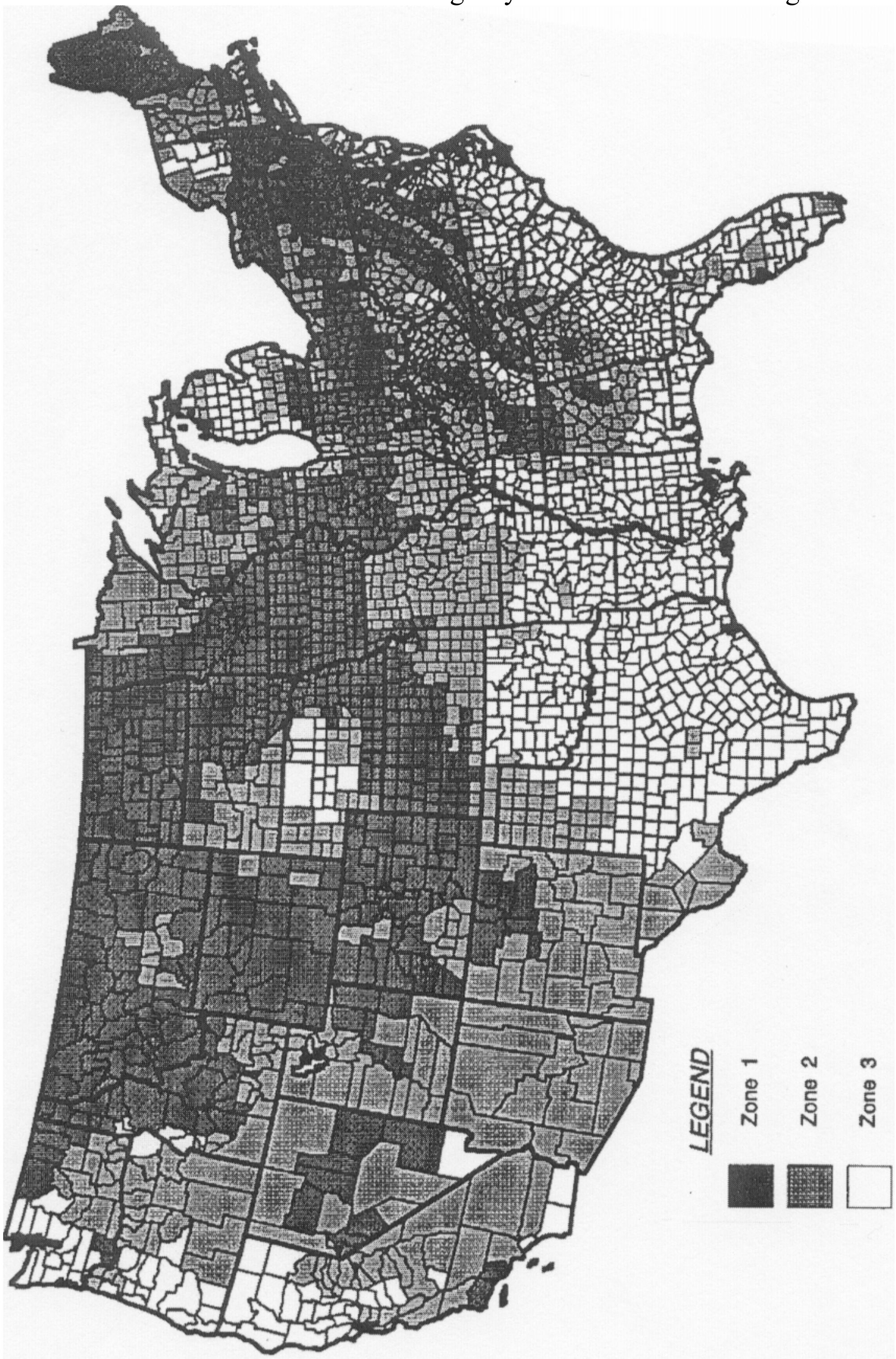
Uranium 238 Decay Chain



The Uranium-238 decay chain, showing the half-lives of the elements and their modes of decay (EPA 1993).

Appendix C

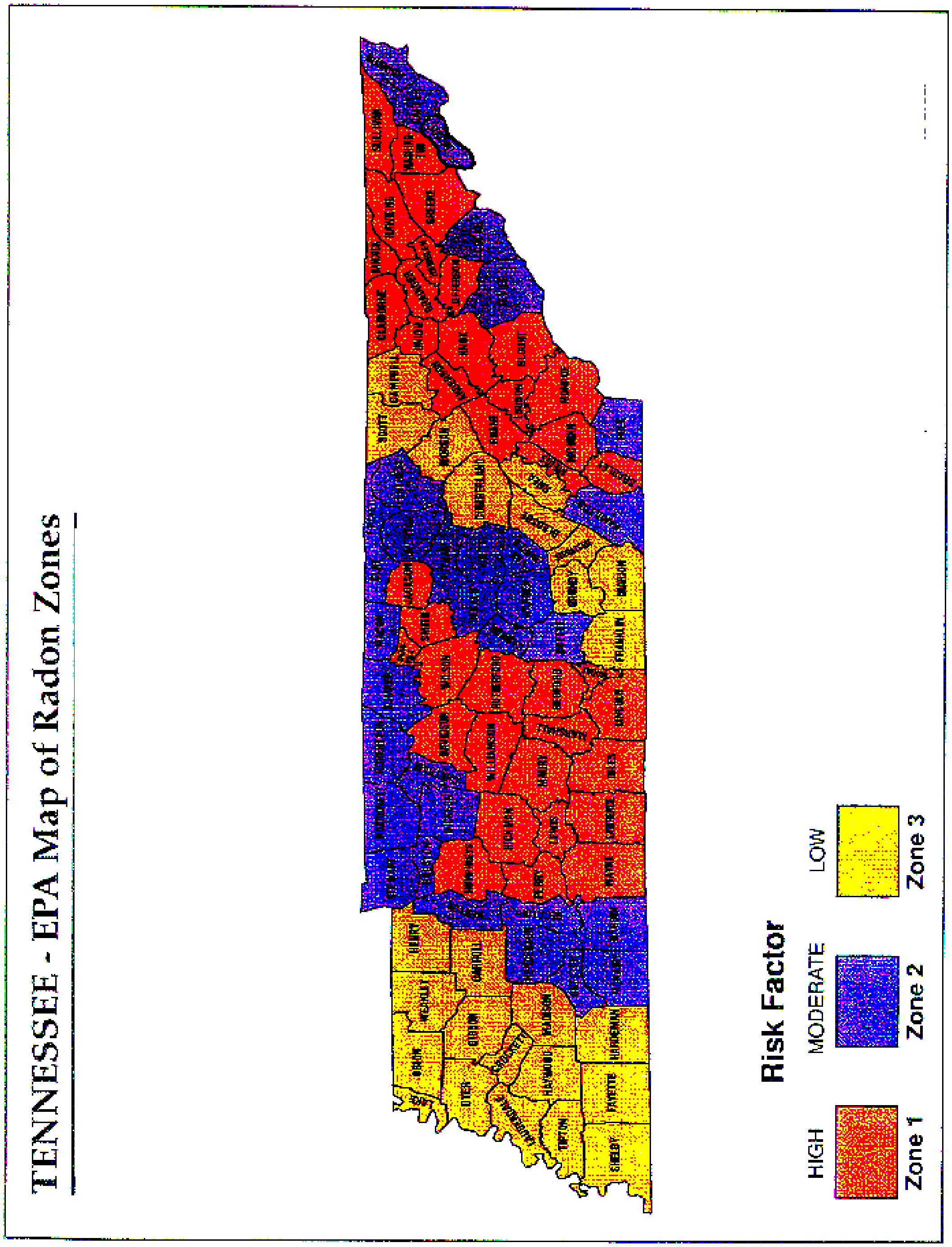
United States Environmental Protection Agency Radon Risk Zone Designation Map



(EPA 1993)

Appendix D

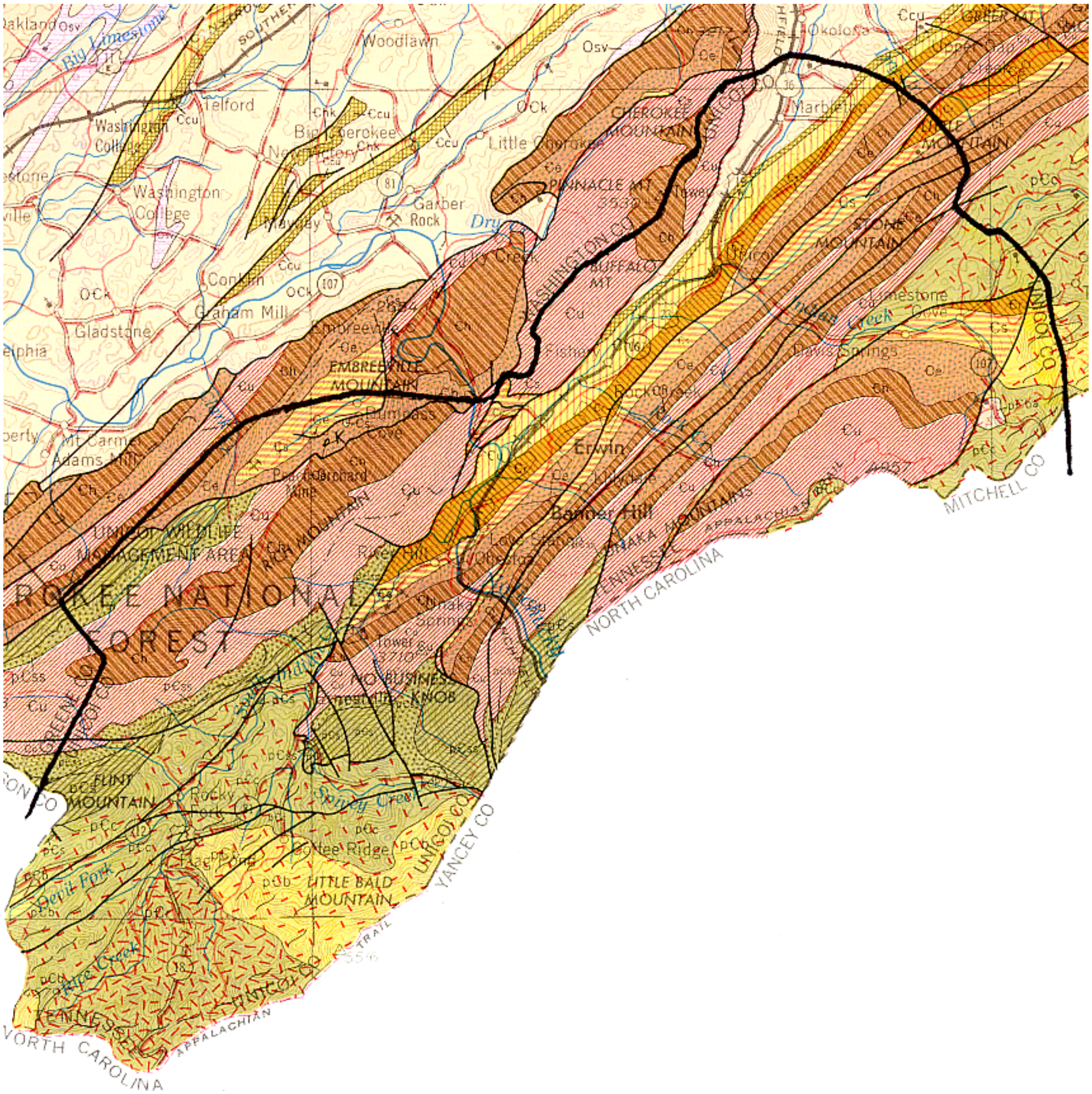
Tennessee Radon Zone Map



(EPA 1993)

Appendix E

Geologic Map for Unicoi County, Tennessee



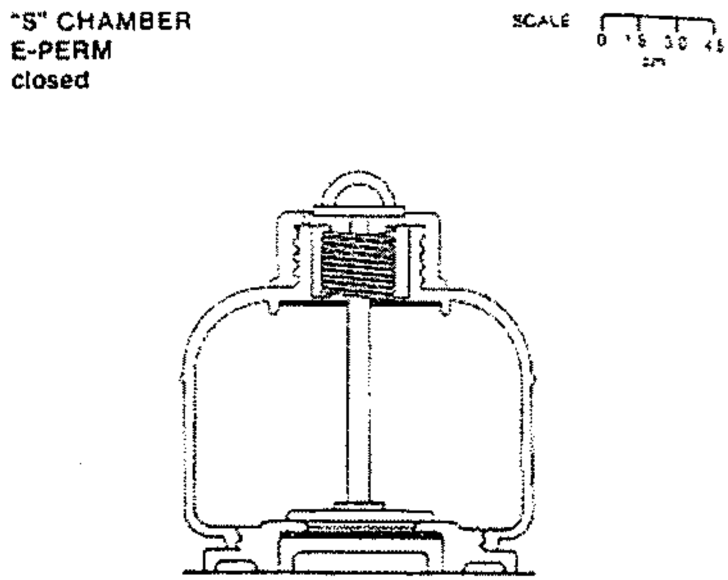
LEGEND	
Honaker Dolomite	Chk
Shady Dolomite	Cs
Erwin Formation	Ce
Rome Formation	Cr

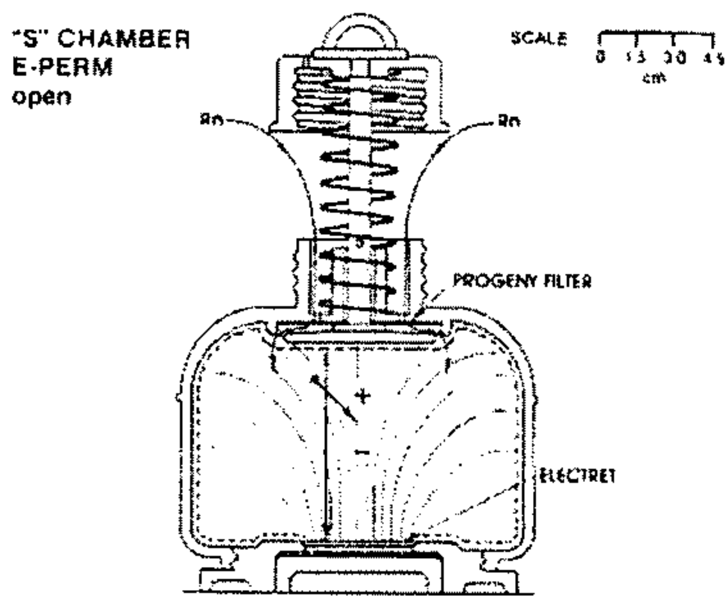
(King and Ferguson 1960)

Appendix F

Schematic of the Electret Passive Environmental Radon Monitor (E-PERM)

"S" Chamber





(Kotrappa 1993)

Appendix G

Electret Passive Environmental Radon Monitor (E-PERM)

Radon Concentration Calculation Formula

Calibration Factor Calculation:

Calibration Factor = 0.14 + 0.0000525 x (initial + final_)/2

Radon Concentration Calculation:

[Rn] = (final – initial) / CF x days - (BG x 0.087) = pCi/L

Example: The initial voltage of the E-PERM electret was 711V. The final voltage after a 104 day exposure was 470 V. What was the average radon concentration?

Calibration Factor = 0.14 + 0.0000525 x (711 + 470)/2

= 0.14 + 0.0000525 x (675)

= 0.14 + 0.03543

= 0.17

Radon Concentration = (700 – 470) / 0.17 x 104 - (10 x 0.087) = pCi/L

= 230 / 17.68 – 0.87

= 13 – 0.87

= 12.13 = picoCuries per liter of air (pCi/L)

Appendix H

United States Environmental Protection Agency Radon Index Matrix Model

TABLE 1. RADON INDEX MATRIX. "ppm eU" indicates parts per million of equivalent uranium, as indicated by NURE aerial radiometric data. See text discussion for details.

INCREASING RADON POTENTIAL →

FACTOR	POINT VALUE		
	1	2	3
INDOOR RADON (average)	< 2 pCi/L	2 - 4 pCi/L	> 4 pCi/L
AERIAL RADIOACTIVITY	< 1.5 ppm eU	1.5 - 2.5 ppm eU	> 2.5 ppm eU
GEOLOGY*	negative	variable	positive
SOIL PERMEABILITY	low	moderate	high
ARCHITECTURE TYPE	mostly slab	mixed	mostly basement

*GEOLOGIC FIELD EVIDENCE (GFE) POINTS: GFE points are assigned in addition to points for the "Geology" factor for specific, relevant geologic field studies. See text for details.

Geologic evidence supporting:	HIGH radon	+2 points
	MODERATE	+1 point
	LOW	-2 points
	No relevant geologic field studies	0 points

SCORING:

Radon potential category	Point range	Probable average screening indoor radon for area
LOW	3-8 points	< 2 pCi/L
MODERATE/VARIABLE	9-11 points	2 - 4 pCi/L
HIGH	12-17 points	> 4 pCi/L

POSSIBLE RANGE OF POINTS = 3 to 17

TABLE 2. CONFIDENCE INDEX MATRIX

INCREASING CONFIDENCE →

FACTOR	POINT VALUE		
	1	2	3
INDOOR RADON DATA	sparse/no data	fair coverage/quality	good coverage/quality
AERIAL RADIOACTIVITY	questionable/no data	glacial cover	no glacial cover
GEOLOGIC DATA	questionable	variable	proven geol. model
SOIL PERMEABILITY	questionable/no data	variable	reliable, abundant

SCORING:

LOW CONFIDENCE	4 - 6 points
MODERATE CONFIDENCE	7 - 9 points
HIGH CONFIDENCE	10 - 12 points

POSSIBLE RANGE OF POINTS = 4 to 12

(EPA 1993)

Appendix I

Electret Passive Environmental Radon Monitor (E-PERM) Certified Readings

Reference Electrets

Rad Elec Inc.

5714-C Industry Lane
Frederick, Maryland 21704 USA
(800) 526-5482 • (301) 694-0011
FAX (301) 694-0013
Web Pages: http://www.radelec.com

CERTIFIED READINGS OF REFERENCE ELECTRETS

Electret #	Date	Reading volts	SPER reader #
R- 1565	2/22/02	233	0110
R- 1608	2/22/02	223	0110

PLEASE READ THE ATTACHED INSTRUCTIONS.

Reference electrets read and certified by:

K. Cage

For Rad Elec Inc.,

Date: 2/22/02

Appendix I continued

Electret Passive Environmental Radon Monitor (E-PERM) Certified Readings

Electret Reader Calibration Certificate

Rad Elec Inc.

5714-C Industry Lane
Frederick, Maryland 21704 USA
(800) 526-5482 • (301) 694-0011
FAX (301) 694-0013
Web Pages: http://www.radelec.com

SPER-1 ELECTRET READER CALIBRATION CERTIFICATE

Calibration Date: 10/11/01

Electret Reader Number: S/N 104

Reference Instrument: FLUKE 23 II, Serial No. ED75

Calibration Conditions: Temperature °F: 77 **Relative Humidity %:** 35

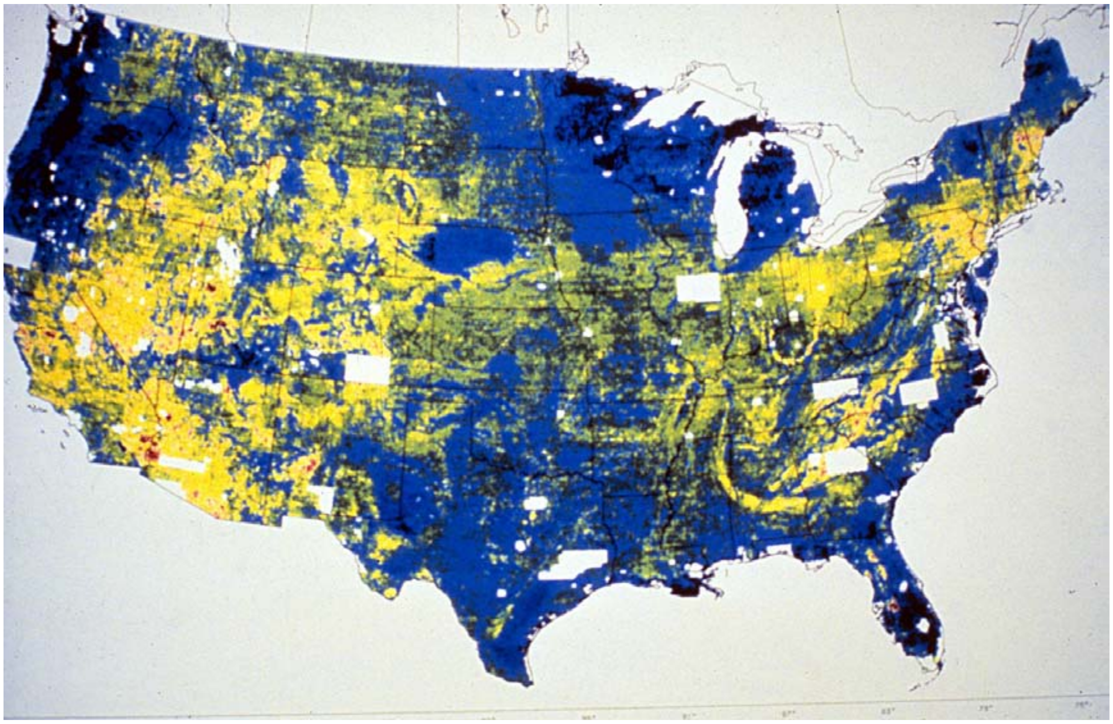
Reference Reading volts	SPER 1 Reading volts
000	000
250	250
350	350
450	450
550	550
650	650
750	750

Rad Elec certifies that the above SPER-1 Reader, s/n: 0104 ***has been calibrated using reference instrument whose accuracy is traceable to the National Institute of Standards and Technology. This reader meets the Rad Elec.'s QA/QC Standards to an accuracy of ±1 volt, as specified in Rad Elec.'s E-PERM System Manual.***

Certifying Technician: Chandrak **Date:** 10/11/01

Appendix J

National Uranium Resources Evaluation (NURE) Map



(EPA, 1993)

Appendix K

Correspondence with W. J. Gains Assessor of Property Unicoi County, Tennessee

ASSESSOR OF PROPERTY
UNICOI COUNTY COURTHOUSE
P. O. BOX 257
ERWIN, TN 37650

March 29, 2003

Mr. Grant Parsons, Graduate Student
East Tennessee State University

Reference: Home Construction in Unicoi County

Dear Grant:

I am pleased to have the opportunity to assist in your research project. In our recent conversation, you inquired about the materials most commonly used in construction of the foundations of homes in Unicoi County. I have been Unicoi County's Assessor of Property since May 1, 1975, and have inspected thousands of new homes in the thirty-one years I have been employed here.

From experience I can tell you that the vast majority of homes being built in Unicoi County are built with a footer extending below the freeze line and concrete blocks extending up to the floor of the dwelling. Many of the homes built in Unicoi County have a basement area constructed of cinder block with a concrete slab floor. If not finished for living area initially, many of these basements are later finished as living area, including family rooms, rec rooms, and additional bedrooms.

Rarely do we see homes resting on posts or piers, as was the case in homes built many years ago. The occasions when we do encounter this type of foundation generally relate to mobile homes, double-wide mobile homes, low end modular homes, or homes in areas that might be subject to flooding.

Likewise, it is uncommon to see houses built on concrete slabs, as may be more common in Florida or South Carolina. It is not uncommon here to find new additions constructed on concrete slabs or former garages and carports with concrete slabs being converted to living area.

I hope this information helps in your research, and I remain at your service if you have further questions.

Sincerely,

W. J. Gaines, Assessor

Appendix L

Radon Contributing Factor Datasets for Unicoi County, Tennessee

2002 Unicoi County Tennessee Radon Study (UCTRS) Data

Radon Monitor Serial #	Concentration pCi/L	Township	Season	Geology
LA 7089	3.2	Erwin	Spring	3
LA 7879	2.3	Unicoi	Spring	1
LA 8374	10	Erwin	Spring	4
LA 8520	2.6	Unicoi	Spring	2
LA 8747	5.2	Unicoi	Spring	1
LB 4769	2.2	Erwin	Spring	4
LB 7082	2.5	Unicoi	Spring	1
LB 7859	3.8	Erwin	Spring	4
LB 7924	2.7	Unicoi	Spring	1
LB 8091	2.6	Erwin	Spring	4
LB 8189	4.8	Erwin	Spring	4
LB 8310	1.5	Erwin	Spring	1
LB 8353	2	Erwin	Spring	1
LB 8494	3	Erwin	Spring	1
LB 8620	1.7	Erwin	Spring	1
LB 8627	5.7	Unicoi	Spring	1
LC 2319	1.7	Unicoi	Spring	1
LC 2413	3.5	Unicoi	Spring	2
LC 4284	2.2	Erwin	Spring	1
LC 5268	2.3	Erwin	Spring	3
LC 7651	3.8	Erwin	Spring	3
LC 7659	1.2	Erwin	Spring	3
LC 7660	3.5	Erwin	Spring	3
LC 7686	15.5	Erwin	Spring	1
LC 7688	1.5	Erwin	Spring	1
LC 7691	2.1	Erwin	Spring	4
LC 7705	1.5	Erwin	Spring	4
LC 7707	11.4	Unicoi	Spring	1
LC 7712	2.6	Erwin	Spring	1
LC 7720	0.6	Unicoi	Spring	1
LC 7731	2.3	Unicoi	Spring	2
LI 4156	3.6	Unicoi	Spring	1
LI 4161	4.7	Erwin	Spring	4
LI 4162	4.9	Unicoi	Spring	1

LI 4167	1.2	Erwin	Spring	4
LI 4169	2.8	Erwin	Spring	1
LI 4197	6.7	Erwin	Spring	1
LI 4198	6.7	Erwin	Spring	2
LI 4206	2.4	Erwin	Spring	3
LI 4207	5.5	Erwin	Spring	1
LI 4212	5.5	Unicoi	Spring	1
LI 4219	2.8	Unicoi	Spring	1
LI 4222	1	Unicoi	Spring	1
LI 4225	5.3	Unicoi	Spring	1
LI 4229	2.7	Erwin	Spring	1
LI 4232	3	Unicoi	Spring	1
LI 4234	2.3	Unicoi	Spring	1
LI 4238	2.3	Erwin	Spring	2
LI 4239	3.2	Unicoi	Spring	1
LI 4241	3.7	Erwin	Spring	2
LI 4242	4.4	Erwin	Spring	3
LI 4244	2.2	Erwin	Spring	4
LI 4258	2.2	Erwin	Spring	4
LI 4264	5.7	Unicoi	Spring	1
LI 4270	14.1	Erwin	Spring	1
LI 4287	6.4	Unicoi	Spring	1
LI 4300	2.8	Erwin	Spring	4
LI 4302	4.5	Erwin	Spring	4
LI 4313	4.1	Unicoi	Spring	1
LI 4317	5.2	Unicoi	Spring	1
LI 4331	5.8	Erwin	Spring	3
LI 4338	2.3	Unicoi	Spring	1
LI4336	11	Unicoi	Spring	1
LJ 7010	1.9	Erwin	Spring	3
LJ 7062	11.2	Unicoi	Spring	1
LJ 7064	7.9	Unicoi	Spring	1
LJ 7081	1.8	Unicoi	Spring	2
LJ 7141	1.3	Unicoi	Spring	3
LJ 7156	1.8	Erwin	Spring	1

Appendix L continued

Radon Contributing Factor Datasets for Unicoi County, Tennessee

1987 United States Environmental Protection Agency (US EPA) Data

Radon Monitor Serial #	Concentration PCi/L	Township	Season
12517	0.7	Erwin	Spring
13377	1	Erwin	Spring
13470	1.7	Erwin	Winter
13474	2	Unicoi	Winter
13497	1.8	Erwin	Spring
13727	2.9	Unicoi	Winter
13824	2.9	Erwin	Spring
14422	4.9	Erwin	Winter
14683	2.1	Erwin	Winter
14844	1.8	Erwin	Spring
14848	1.9	Unicoi	Spring
14887	1.6	Erwin	Spring
14898	0.5	Erwin	Spring
15888	1.7	Erwin	Winter

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Education:

8/00- 8/03 M.S. in Environmental Health, East Tennessee State University, Johnson City TN
8/83 -5/91 B.S. in Biological Sciences, Appalachian State University, Boone NC

Experience:

9/02-present Environmental Consultant, Schreiber and Associates LLC

- Site assessments
- Wrote spill prevention and containment plans
- Educate clients on spill prevention regulations

6/01-2/03 General Partner Agent, Tennessee Radon Program

- Designed and enacted public awareness program
- Wrote research Grant

8/00-5/03 Graduate Assistant, East Tennessee State University,
Department of Environmental Health

- Field and Laboratory Research
- Guest Lectured in Classes for:
  - Indoor Air
  - Industrial Safety
  - Shelters Environment

Presentations:

Parsons, Wm. G. and Maier, K. J. Indoor Radon in Unicoi County, Tennessee. Presented at the 1992 Environmental Health Seminar Series.

Research Experience:

9/00-8/03 Re-evaluation of the US EPA Radon Risk Categorization Matrix Model including; obtainment of funds, conducted participant interviews, monitored 69 homes, following all established QA/QC, performed statistical procedures and wrote a detailed manuscript.

4/02-2/03 Assisted in the study of long-term impacts of road construction on fish communities and water quality parameters

4/02-8/02 Assisted in Water quality analysis for Tennessee Valley Authority area lakes

9/02-12/02 Assisted in Indoor Air Bioaerosol survey, for the American Red Cross

Certifications/ Training:

Radiation Safety Certification Training, East Tennessee State University
Responsibility in Human Subject Research, Internal Review Board,
East Tennessee State University
Residential Radon Measurement Provider, National Environmental Health Association
Residential Radon Mitigation Provider, National Environmental Health Association
Tennessee Radon New Construction Training, Southern Regional Radon Training Center

Funding:

Conference of Radiation Control Program Directors, Radon Awareness Mini-Grant Award

Service:

Student National Environmental Health Association

References:

Available Upon Request